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(54) Ion detector.

(57) An ion detector is disclosed herein and includes a conversion dynode for receiving at its input charged particles and for delivering at its output charged particles such that the latter particles leave the output of said dynode in a diffused manner and a microchannel electron multiplier disposed adjacent the conversion electrode to receive said diffused charged particles from the output of the conversion dynode and a collector electrode for receiving electrons exiting the microchannel plate. The ion detector also includes a resistive divider for providing voltages to said conversion dynode, across the microchannel plate and to said collector electrode.

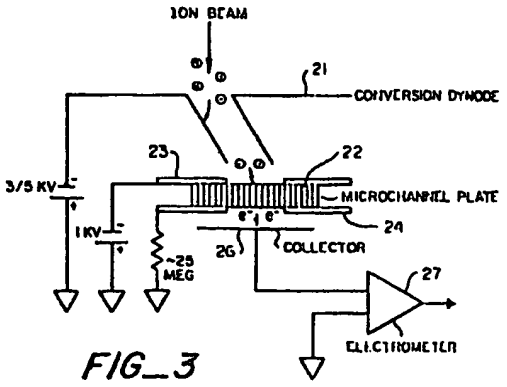

FIG_3

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" ION DETECTOR "

This invention relates generally to an ion detector and more specifically to an ion detector particularly useful for detecting ion beams in mass spectrometers.

Devices which are used to convert the kinetic energy of an accelerated ion beam in a mass spectrometer into electrical signals are well known and commonly called ion detectors. There are several types of known ion detector devices: Faraday cup detectors; electron multipliers of the discreet or continuous dynode type; conversion dynode systems followed by an electron multiplier and ion-to-electron converter followed by an electron-to-photon converter.

The most commonly used mass spectrometer detectors are electron multipliers. They operate in a vacuum system, have a gain factor of about 10^5, have a lifetime with relatively stable gain of about one year and are relatively compact. When used with a conversion dynode such as shown in Patent 4,423,324, both negative and positive ions may be detected with the same device by changing the polarities of the voltages applied to the conversion dynode.

Referring to Figure 1, this type of prior art device is shown. The device works in the following manner: Positive ions 11 emerging from the exit of the mass spectrometer are accelerated by a negative potential applied to the surface

of the conversion dynode 12. The ions strike the dynode, which produces charged particles. Negative charges 13 are attracted to the front surface of the electron multiplier 14 by the voltage applied to the upper plate of the electron multiplier. It is to be noted that this negative voltage is substantially less than the negative voltage on the conversion dynode whereby to accelerate the electrons toward the electron multiplier. Amplification takes place within the multiplier and the resulting signal is brought from the vacuum system to an external amplifier 16 for signal processing. When the voltage applied to conversion dynode 11 is positive, as shown in Figure 2, then negative ions 17 are attracted to the surface of the dynode and a process of charge conversion takes place. Positive charges 18 are formed and attracted to the front surface of the electron multiplier and multiplied as before with the output signal being applied to the amplifier 16.

It is an object of the present to provide a compact detector having the ability to detect both positive and negative ions and which is relatively low in both initial and replacement costs.

The detector of the present invention uses one or more microchannel plates as the electron multipliers cooperating with a conversion dynode.

Referring to the drawings:

Figure 1 is a schematic diagram of an ion detector including a conversion dynode and multiplier in accordance with the prior art for detecting positive ions.

Figure 2 is a schematic diagram of an ion detector including a conversion dynode and electron multiplier in accordance with the prior art for detecting negative ions.

Figure 3 shows an ion detector in accordance with the present invention employing a conversion dynode and microchannel

electron multiplier plate.

Figure 4 shows a system for testing the linearity of the detector shown in Figure 3.

Figures 5 and 6 show the dynamic range of an ion detector in accordance with the present invention.

Figure 7 shows a resistive divider for providing voltages for the detector.

Referring to Figure 3, the ion detector in accordance with the present invention consists of a conversion dynode 21 which is biased at either a high positive or high negative potential and which converts negative or positive ions to positive or negatively charged particles as previously described. Closely spaced from and in cooperation with the output of the conversion dynode 21 is a microchannel plate 22. The microchannel plate has a voltage applied thereacross and acts as an electron multiplier. The voltage is applied across the microchannel plate by making electrical contact 23 and 24 to its upper and lower bases.

Microchannel plate multipliers are well known. They have been described in a number of articles, for example, in the article by G. W. Goodrich and W. C. Wiley, "Review of Scientific Instruments," 32, 846, (1961); ibid, 33, 761, (1952). Microchannel plates are manufactured by Galileo Electrooptics Corporation, Mullard, Ltd., Varo Electron Devices, and ITT Electrooptics Division among others. They are used in a variety of products as amplification devices and details of operation, construction and application are given in articles by J. L. Wiza, "Nuclear Instruments and Methods, Vol. 162, pages 587 (1979); J. Cortez and B. Laprade, "Long Life Microchannel Plate" paper No. 418, Thirty-fifth Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 3, 1984. Basically, in operation, each of the microchannels tubes in the microchannel plate acts as a

continuous dynode multiplier with charged particles entering one end of the channel dislodging secondary electrons. The secondary electrons are then accelerated down the channel tube by the external voltage applied across the channel plate with sufficient energy to dislodge additional secondary electrons, thus producing electron multiplication of up to millions of times for each primary electron.

In accordance with the present invention, the ion beam which strikes the dynode forms many particles which impinge upon the microchannel plate surface in a diffused manner, over a large area, rather than as a focussed beam on a small number of channels. This increases both the dynamic range and lifetime of the microchannel plate as an electron multiplier as compared to use without the conversion dynode. The lower part of the microchannel plate is biased negatively with respect to a collector plate 26 allowing electrons exiting the microchannel plate to be attracted to the signal collector plate. The current is applied to an electrometer 27 or other amplifier.

When microchannel plate detectors have been used in the past for detection of ion beams, they have not performed satisfactorily and linearly because the beam is concentrated on a small number of channels and the channels become saturated. Further, the intense beams striking the channel plates have shortened the life of those small number of channels upon which the beam impinges. Further, the voltage gradient to which the impinging ions are subjected is limited to the voltage applied to the microchannel plate. Thus, Applicant has not only provided additional amplification by use of the conversion dynode, but by use of the conversion dynode has spread the charged particles which strike the microchannel plate to thereby improve linearity and lifetime. Furthermore, the use of a conversion dynode allows application of voltages such that impinging ions will have increased energies over those ions accelerated to a channel plate alone,

and the more energetic ions will have increased probability of fragmentation.

In certain instances it may be desirable to obtain additional amplification. In such an instance, multiple channel plates may be used, one following the other, whereby the electron beams emerging from the first channel plate strike the second channel plate and are amplified by the second channel plate prior to the electrons striking the collector plate.

It is important that any detector system have a dynamic range which will cover expected signal levels even in the presence of a large matrix background. That is, it should have ability to produce an output signal proportional to concentration of a component over three decades of concentration, even when the component is a fraction of a percent of the other components present.

An ion detector in accordance with the present invention was constructed and tested. The test set up is shown in Figure 4. The exponential dilution flask was purchased from Varian Aerograph. In the experiment helium carrier gas was set to 10 psi by the pressure regulator. The flask was stirred by means of a magnetic stirrer, in order to mix the sample with the eluting gas. Leak No. 1 was adjusted so that the exiting flow from the flask was about 50cc per minute. The flow into the mass spectrometer, with valve 1 open, was adjusted by Leak No. 2 until the indicated pressure was 4×10^{-5} torr. The actual valves of flow were measured by means of a soap bubble meter, making measurements with Valve 1 open and closed. The difference in measured flows is the flow into the mass spectrometer, which was about 2.7 cc per minute. A sample of argon gas was injected into the dilution flask, and the intensity of the argon peak (m/e = 40) was monitored as a function of time. Two methods of monitoring were used: 1) The spectrum from m/e 26 to 45 was recorded on a two pen strip chart recorder,

using a 100-second scan, every two minutes. 2) The intensity of the m/e = 40 peak was continuously monitored, using a Keithley model 614 electrometer, with readings being taken as a function of time. Data was plotted on semilog paper, with correction being made for background argon. Data from the recorder traces was measured with a ruler as peak height, and normalized. Electrometer data was plotted in nanoamps. No attempt was made to calculate the absolute amount of sample present.

Figure 5 is a plot of the electrometer data. The background value for m/e = 40 was 0.48 nanoamps, being due to residual air leaks in the system. (Base pressure was 2×10^{-6}.) This was subtracted from the measured reading; both corrected and uncorrected readings are shown. The initial lag between the time the sample (1 ml argon in 275 ml flask) was injected and when maximum intensity was recorded is due to the volumes of the system, especially the Granville-Phillips leak valves. Again, absolute quantities were not determined.

The strip current for the detector with 1,000 volts across it, is 2.1 uamps. The manufacturer's literature states that the output current becomes non-linear above 10 percent of this value, or 210 nanoamps. This point is drawn on the graph. Some deviation from a straight line is indicated on Figure 1 at the high end, which had a maximum value of 120 nanoamps. Part of this may be due to the time constant of the measuring system.

Figure 6 is data taken by scanning over the m/e = 40 peak and measuring the peak height in millimeters from the recorder trace. The plot is peak height in mm, normalized to a recorder sensitivity of 1 mv, vs time. Background correction was made by subtracting the value of the residual m/e = 40 peak. This scale corresponds to 0.51×10^{-12} amps/mm, and the maximum peak current is 50.6 nanoamps (a factor of 2.5 lower than Figure 1). The result is a straight

line with over three decades of linear dynamic range. Since background peaks were also scanned, the values for m/3 = 44 are also included, showing a system stability during this measurement.

Thus it is seen that the detector system of the present invention has the necessary dynamic range, even with high background gas pressures.

The microchannel plates may have a temperature coefficient of resistance. Thus, if the relative voltages of the dynode, microchannel plate and collector are obtained from a single power supply by means of a resistive voltage divider, the temperature coefficients of the various resistors should be matched so that the voltage ratios remain constant with temperature. Such an arrangement is shown in Figure 7 with the divider formed by resistors 31, 32, and the resistance of the microchannel plate.

The design of the ion detector may provide for moving the microchannel plate to expose different portions of plate to the ions from the dynode so that as one area wears another area may be used. Alternately, the design may be such that microchannel plates may be replaced after a predetermined period of time for surface renewal without complete disassembly of detector structure.

Another feature of this structure is that when separate power supplies are used the dynode and multiplier may have voltages applied such that the gain can be greatly changed by lowering the voltage applied to the dynode to be equal to that of the microchannel plate which allows the current through the microchannel plate to remain constant while reducing the gain of the system.

Thus there has been provided an improved, compact, linear ion detector for use in mass spectrometers and the like.

CLAIMS:

1 An ion detector comprising a conversion dynode for receiving at its input charged particles and for delivering at its output charged particles such that the latter particles leave the output of said dynode in a diffused manner and a microchannel electron multiplier disposed adjacent said conversion electrode to receive said diffused charged particles from the output of the conversion dynode and a collector electrode for receiving electrons exiting the microchannel plate.

2. An ion detector as in Claim 1 including a resistive divider for providing voltages to said conversion dynode, across said microchannel plate and to said collector electrode.

3. An ion detector as in Claim 2 in which the resistive network has a temperature coefficient of resistance matched to that of the microchannel plate.

4. An ion detector as in Claim 1 in which two microchannel plates in series are used as electron multipliers.

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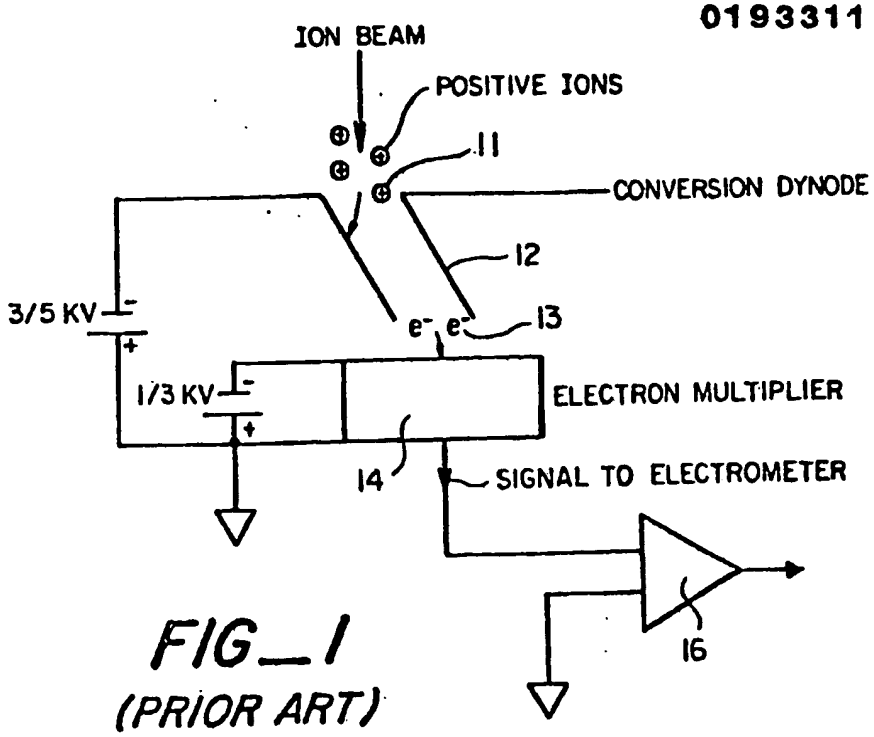

FIG_1
(PRIOR ART)

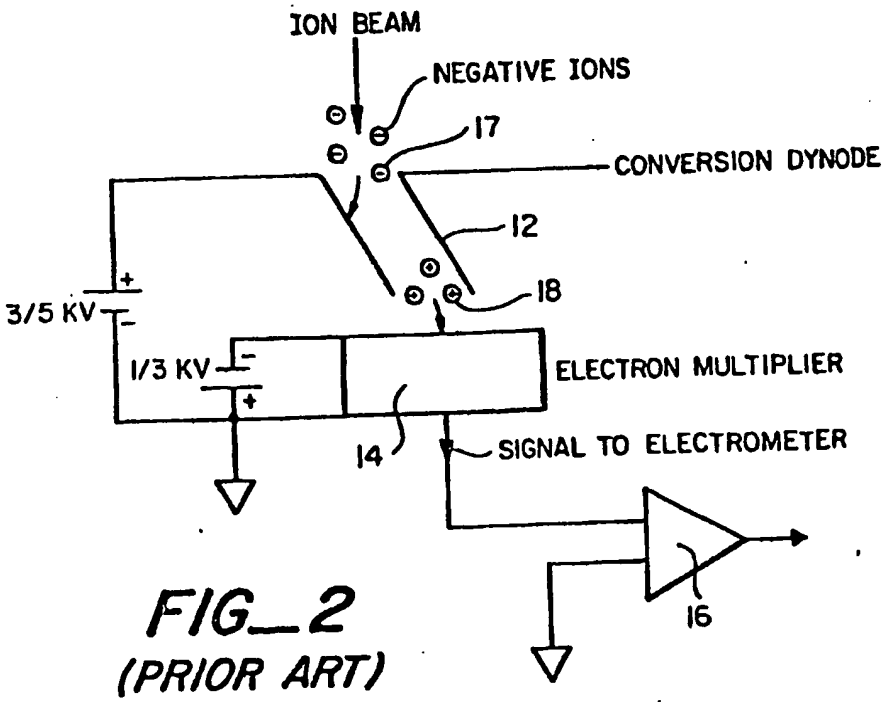

FIG_2
(PRIOR ART)

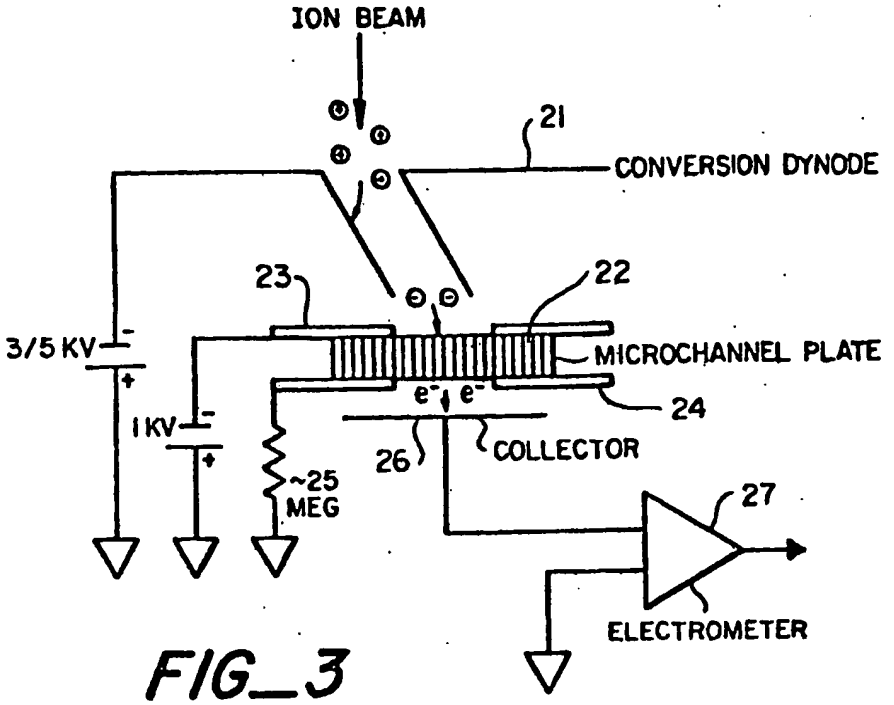
ION BEAM
21
CONVERSION DYNODE
23
22
3/5 KV
MICROCHANNEL PLATE
e⁻ e⁻
24
1 KV
26
COLLECTOR
~25 MEG
27
ELECTROMETER

FIG_3

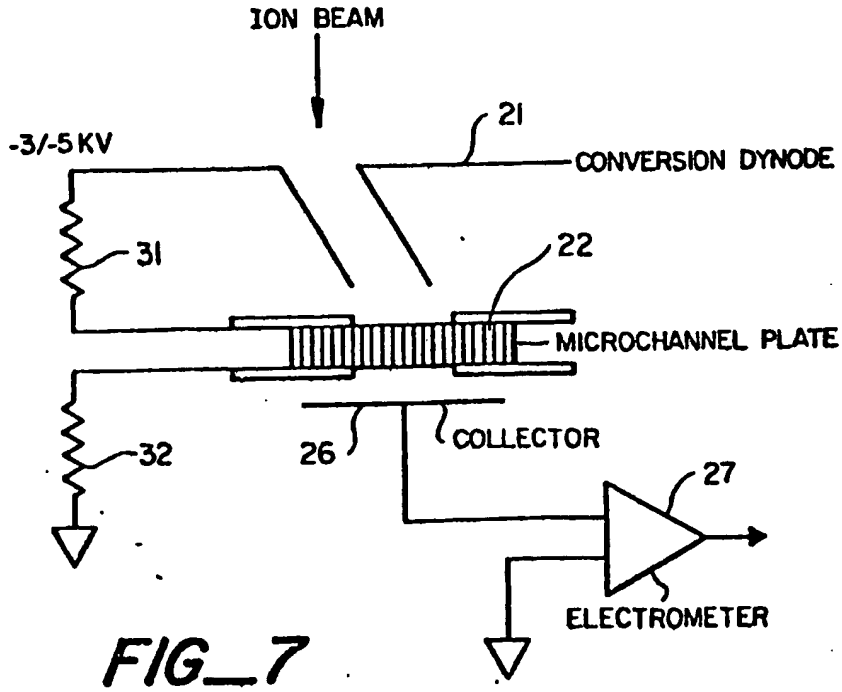
ION BEAM
21
-3/-5 KV
CONVERSION DYNODE
31
22
MICROCHANNEL PLATE
26
COLLECTOR
32
27
ELECTROMETER

FIG_7

12

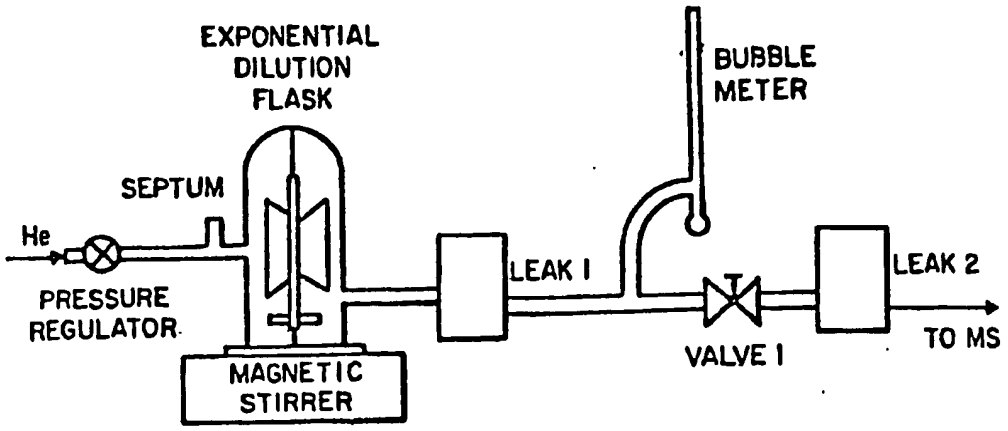

FIG_4

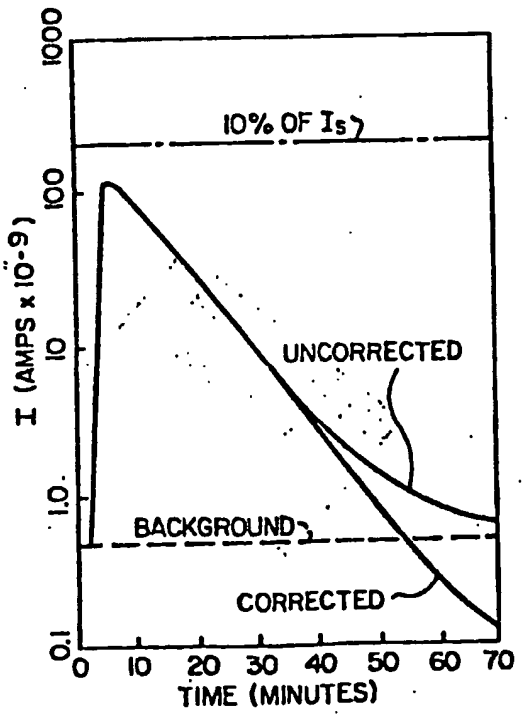

FIG_5

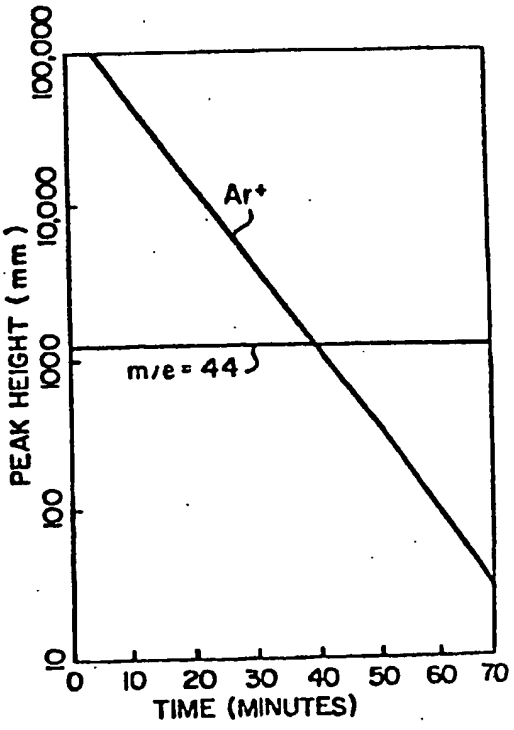

FIG_6